

Strategic Role of Sustainable Digitalization in Driving the Green Transition

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Abstract

The accelerating global transition toward climate neutrality requires the integration of digital technologies with sustainability strategies, as economies face both decarbonization imperatives and digital transformation. Despite the recognized potential of digital tools, their systemic role in supporting the green transition remains insufficiently conceptualized. This study aims to develop a conceptual framework for sustainable digitalization as a strategic driver of the twin transition toward a climate-neutral global economy. The research combines system analysis with empirical evaluation of international climate-digital projects drawn from open climate databases. This approach integrates theoretical foresight analysis and project-based classification to identify key accelerators of sustainable digitalization. The findings demonstrate that digital technologies such as artificial intelligence, blockchain, big data analytics, and the Internet of Things can reduce emissions, optimize resource use, and foster inclusive innovation ecosystems. Eight categories of digital accelerators were identified, which significantly contribute to climate resilience, transparency, and mass cooperation across sectors, including energy, agriculture, transport, and industry. The study concludes that sustainable digitalization is not merely a technological trend but a structural enabler of climate neutrality. Its success depends on coordinated international frameworks, policy coherence, and inclusive digital access. The results provide evidence-based recommendations for policymakers and stakeholders, emphasizing the need to prioritize sustainability-by-design in digital innovation, to ensure transparent governance together with standardized data infrastructures, and to strengthen digital education as a foundation for equitable participation. By doing so, digitalization can serve as a transformative accelerator of long-term climate neutrality and global economic resilience.

Keywords

Sustainable digitalization; Climate neutrality; Green transition; Innovations; Sustainable development

Introduction

In the contemporary global landscape, the economy faces unprecedented challenges in achieving climate neutrality and fostering sustainable development. Driven by international initiatives aimed at reducing greenhouse gas emissions and mitigating climate change, governments, corporations, and society at large are actively implementing strategies to minimize environmental impact (European Commission, 2023). Simultaneously, the advancement of digital technologies presents new opportunities to support these objectives by optimizing industrial and economic processes, enhancing resource efficiency, and reducing overall energy consumption (Rolnick *et al.*, 2022; Santarius, Pohl and Lange, 2023).

Sustainable digitalization is becoming increasingly significant as the rapid expansion of digital technologies profoundly influences global energy consumption patterns. While digital innovations offer substantial potential for reducing emissions and improving energy efficiency, they also introduce new environmental pressures due to the escalating demand for energy and raw materials required for the production and maintenance of digital infrastructure. Furthermore, without a globally coordinated regulatory framework and the integration of sustainability principles into digitalization processes, the digital transition may exacerbate environmental challenges. This includes heightened carbon emissions from energy-intensive information and communication technology (ICT) services, as well as a growing volume of electronic waste (Radvilė and Urbonas, 2025; Zhao *et al.*, 2024). Moreover, the social dimensions of the dual transition must be considered, as disparities in access to digital technologies between developed and developing nations risk deepening global inequalities and impeding collective efforts toward climate neutrality. Scholars emphasize that without a globally coordinated regulatory framework and the integration of sustainability principles into digitalization processes, the twin transition may exacerbate rather than resolve environmental challenges (Petmesidou and Guillén, 2022; Roussilhe, 2025).

Against this backdrop, sustainable digitalization emerges as a strategic paradigm that seeks to harmonize the digital and green transitions. By embedding sustainability principles into digital innovation, this approach addresses both environmental imperatives and socio-economic inclusivity. Establishing a balanced framework that integrates digital technologies with green policies will be fundamental to achieving long-term climate goals while fostering resilience and equity in the global economy. However, despite the growing academic interest, research gaps remain. First, most existing studies focus either on technological opportunities or on environmental policy aspects, but rarely analyze their systemic convergence. Second, there is insufficient empirical evidence on how digital technologies are already being embedded into climate-related projects worldwide. Third, the strategic role of sustainable digitalization in harmonizing global efforts toward climate neutrality remains underexplored, particularly in terms of long-term innovation trajectories and governance models (Hedberg and Sipka, 2021; Pietrón, Staab and Hofmann, 2022).

Accordingly, the objective of this study is twofold:

- on the one hand, to develop a conceptual framework for sustainable digitalization as a strategic driver of the twin green and digital transitions;
- on the other hand, to empirically validate the role of digital accelerators in fostering sustainability through the analysis of international climate-digital projects.

Review of Literature

The current scientific discourse encompasses numerous international studies that examine the digital and green transitions both independently and in their interdependent relationship. However, the conditions, mechanisms, and, most importantly, the long-term consequences of their alignment in the context of achieving climate neutrality in the global economy remain insufficiently explored. Existing studies can be broadly grouped into three thematic strands.

First, a substantial body of research highlights the technological contributions of digitalization to the green transition. A growing body of both applied and fundamental research investigates the role of digital technologies in reducing greenhouse gas emissions within contemporary economic systems. In their research, Santarius T. Dencik L. and other scientists analyze the impact of digitalization on sustainable development, highlighting its potential to significantly reduce emissions through automation, process optimization, decreased energy consumption, and improved resource management via smart grids and the Internet of Things (Santarius *et al.*, 2023). Similarly, Rolnick *et al.* (2022). underscore the transformative potential of machine learning technologies in combating climate change by enhancing energy efficiency and optimizing the integration of renewable energy sources. Studies by Hedberg A., Pietrón D., Staab P., and Hofmann F. emphasize the role of digitalization in fostering a circular economy; their findings illustrate how digital innovations can optimize supply chains, promote material reuse, and create sustainable markets, thereby contributing to emissions reduction (Hedberg and Sipka, 2021; Pietrón, Staab and Hofmann, 2022). Beyond technological innovations, some scholars stress the importance of shifting societal behaviors toward more environmentally conscious lifestyles, recognizing this transformation as a fundamental component of sustainable development (Frick *et al.*, 2021; Santarius, Pohl and Lange, 2020).

Second, another stream of literature focuses on governance and policy frameworks that shape the integration of digital and green agendas. An increasing number of influential international organizations and individual scholars have significantly advanced the conceptual and empirical understanding of green technological innovation as a core driver of long-term climate resilience and economic competitiveness. Among these, several key contributions deserve particular attention. The International Institute for Applied Systems Analysis (IIASA, 2020) provides a comprehensive systems-level analysis of how digital transformation intersects with the United Nations Sustainable Development Goals. The report emphasizes both the opportunities and critical risks of digitalization, including its potential to widen global inequalities or exacerbate environmental degradation if not properly governed. It advocates for a holistic governance architecture that integrates sustainability metrics into digital innovation cycles. The ECS Strategic Research and Innovation Agenda (ECS SRIA, 2023) stresses the integration of sustainability-by-design principles into electronics, components, and

systems engineering toward climate-resilient applications in manufacturing, energy systems, mobility, and smart environments. This marks a shift from post-facto environmental assessment to proactive sustainability integration. Another research rethinks the initiative “Made in Europe” (EFFRA and European Commission, 2021), highlighting the strategic alignment of digitalization with decarbonization in industrial processes, focusing on automation, resource-efficient production, and circularity.

Third, several studies address socio-economic and behavioural perspectives, demonstrating how digitalization intersects with entrepreneurship, well-being, and inequality. On the academic side, scientific findings support the thesis that green entrepreneurship thrives in environments where digital infrastructures and sustainability policies are aligned (Vasilescu, Dimian and Gradinaru, 2023). Moreover, AI, IoT, and blockchain are revealed as crucial technologies for green via digital convergence, not only as efficiency tools but also as mechanisms of governance transformation, transparency, and stakeholder engagement in the green transition (Maksymova *et al.*, 2023). Brych *et al.* (2025) also expand the discussion by linking green innovation to socio-economic well-being. Goven model examines how remuneration systems, employment dynamics, and human capital interact with the deployment of innovative digital technologies.

Despite the substantial scale of research on green and digital transformation, most existing studies remain sector-specific, focusing either on technical aspects of individual industries or on isolated elements of the green or digital transition. The question of their systemic synergy and strategic role remains an open and pressing topic within scientific discourse.

Methodology

The methodological design of this study consisted of two interlinked stages with an intermediate sub-stage, combining theoretical exploration with empirical analysis and ensuring both conceptual rigor and practical reproducibility.

Theoretical–analytical groundwork

At the first stage, system analysis was applied to structure existing scientific knowledge on the interrelation between digitalization and sustainability. This stage relied on document analysis of international foresight reports and policy papers (e.g., EU Strategic Foresight, ECS SRIA, IIASA reports) as the primary research tool. A content mapping technique was used to extract and categorize recurring themes, which facilitated the identification of stigmatic threats to the twin transition, such as the digital divide, the energy intensity of digital technologies, dissonance in policy frameworks, and financial barriers. This step positioned the need for harmonization of the green and digital transitions and emphasized sustainable digitalization as a bridging concept.

Identification of required digital innovations

Before moving to the empirical analysis, an intermediate step was undertaken to clarify what types of digital innovations are necessary for the green transition. This sub-stage

employed foresight analysis and case study review of official European Commission documents, which serve as flagship references for the twin transition. These methods enabled the identification of sectoral directions of innovation in agriculture, energy, construction, heavy industry, and transportation. Tools such as comparative sectoral analysis were applied to specify critical digital technologies for decarbonization (e.g., smart farming, digital twins, hydrogen production, BIM, autonomous vehicles). This sub-stage thus linked the conceptual framework with practical innovation pathways, providing the basis for operationalizing the empirical analysis.

Empirical project analysis

At this stage, the research focused on project-level data using empirical systematization techniques:

- 1) Database selection and extraction. The study relied on the open-access database Sustainability in the Digital Age (SDA, 2025), which aggregates 370 international projects that explicitly combine climate objectives with digital technologies. A particular advantage of this database is its comprehensive structure and accessibility, as it provides detailed project portfolios together with a wide tabular editor containing aggregated statistics. For each project, the database offers standardized information on the region of implementation, stakeholders involved, project scale, and the digital technologies applied. This level of detail ensured consistency in data collection and allowed for the forthcoming systematic grouping and classification across sectors.
- 2) Grouping and systematization. Projects were organized within sectoral domains: energy, agriculture, transport, industry, environmental monitoring, and circular economy practices.
- 3) Accelerator framework. The classification started from the four baseline accelerators proposed by Chuard *et al.* (2022), namely: transparency, intelligent systems, augmented reality, and mass cooperation. Based on the project portfolio analysis, this typology was further expanded to include additional accelerators such as smart personalization, blockchain-based decentralization, synergistic platforms, and digital education.
- 4) Classification process within the accelerator framework. Projects were assigned to one or more categories of digital accelerators according to their impact and performed digital innovations. Discrepancies were resolved through discussion until consensus was reached. Cross-checking was performed, and random samples of classified projects were re-evaluated. Agreement levels above 90% confirmed the consistency of classification.

Thus, the application of system analysis allowed for structuring existing knowledge, identifying stigmatic threats, and developing the conceptual model of sustainable digitalization. The use of grouping enabled the organization of projects by sectors and thematic domains, ensuring a coherent empirical base. Finally, the application of classification made it possible to map projects to digital accelerator categories and validate the theoretical assumptions, thereby establishing a solid link between conceptual findings and empirical evidence.

Results

The twin transition, encompassing both digital and green transformations, represents a coordinated and systematic integration of digital and environmental technologies within the broader framework of fostering sustainability across industrial, social, and economic systems. These two transformative paradigms are inherently complementary, collectively advancing key objectives such as reducing greenhouse gas emissions, enhancing energy efficiency, and fostering the deployment of innovative technologies. However, the successful implementation of this twin transition necessitates a structured approach to harmonization, ensuring alignment with the long-term objective of achieving global climate neutrality. This requirement arises from the presence of identified groups of negative impact factors that may hinder progress toward a greener future of the world economy (Figure 1).

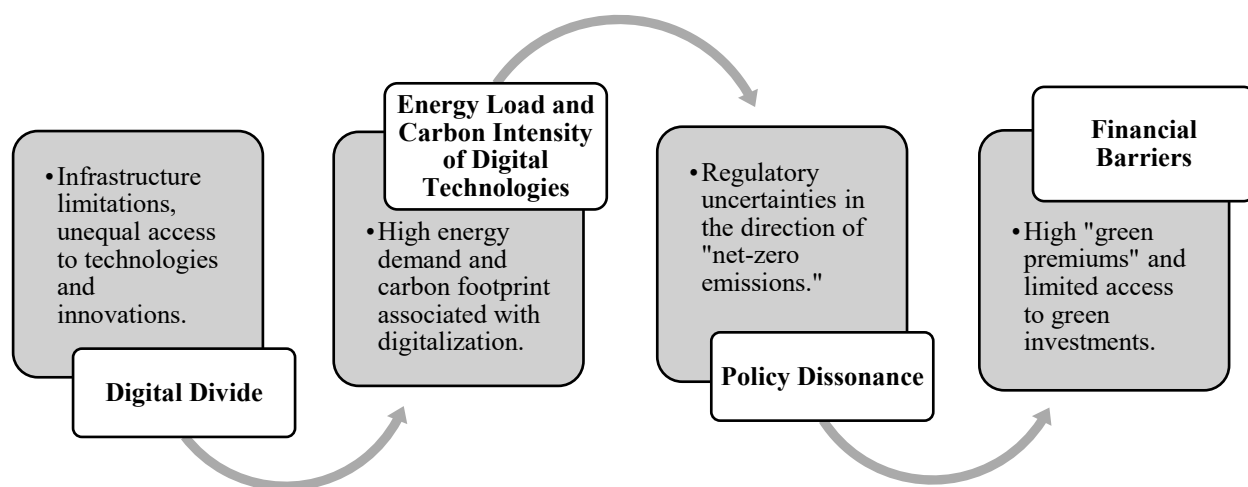


Figure 1: Stigmatic threats of the digital-green transition

As illustrated in figure 1, the stigmatic threats of the digital-green transition highlight systemic vulnerabilities such as the digital divide, high energy intensity of ICT, and fragmented policy frameworks. These barriers exhibit a stigmatizing character in socio-economic terms, reinforcing structural inequalities and creating systemic barriers that hinder the effectiveness of the green-digital transition toward achieving climate neutrality in the global economy. The digital divide remains a critical constraint, as underdeveloped digital infrastructure and limited access to advanced technologies disproportionately affect regions with inadequate Internet coverage and low-quality communication networks, exacerbating disparities in digital transformation (Diodato *et al.*, 2023). Moreover, despite the substantial potential of digital technologies to accelerate green development, their deployment also imposes a significant energy burden. The high energy consumption associated with artificial intelligence, blockchain, and other data-intensive technologies raises concerns regarding their alignment with decarbonization goals, potentially undermining efforts to reduce emissions in energy-intensive sectors (EIT Digital, 2022; Radvilė and Urbonas, 2025; Zhao *et al.*, 2024).

Another pressing challenge is the lack of regulatory clarity and strategic policy coherence. The absence of well-defined, long-term regulatory frameworks and specific targets that integrate digitalization into climate-neutrality strategies creates uncertainty for businesses and investors, thereby slowing down the transition process and limiting the mobilization of financial resources for sustainable innovation (Petmesidou and Guillén, 2022).

Thus, the harmonization of the green-digital transition necessitates strengthening synergies between digital and environmental policies to ensure their convergence in fostering broad-based emissions reductions and advancing the climate-neutral transformation of the global economy. To this end, the following three-level model of harmonization of the digital-green transition towards climate neutrality of the global economy is proposed (Figure 2).

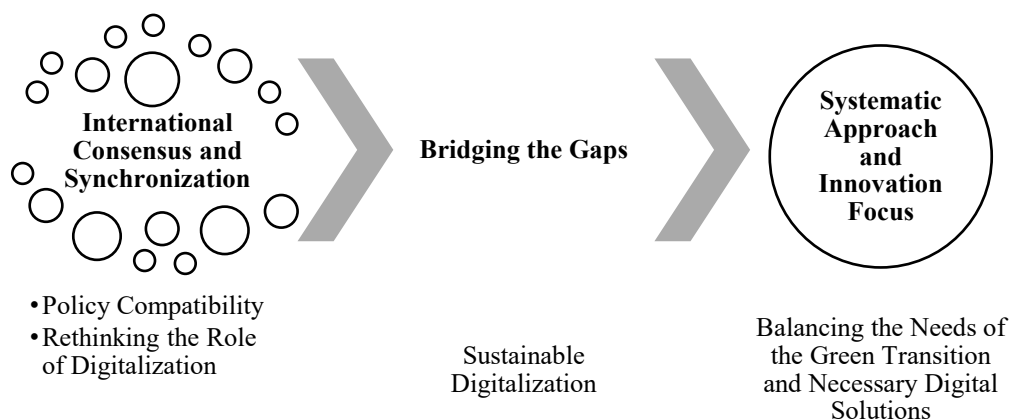


Figure 2: Three-dimensional strategic role of sustainable digitalization in achieving the green transition

Figure 2 presents the proposed three-level model of harmonization. This framework demonstrates how sustainable digitalization can bridge global policy objectives, innovation ecosystems, and digital access, thereby aligning the green and digital transitions. The first dimension of sustainable digitalization in the green transition focuses on building international consensus on climate neutrality and redefining the role of digitalization in this process. This requires convergence among countries toward net-zero emissions, the global development of digital competencies, and the integration of sustainability principles into digital transformation. Key components include cross-sectoral innovation ecosystems, the alignment of global policies with national interests, and the establishment of universal norms and standards. The significance of this component has been repeatedly emphasized in academic literature and supported by the findings of multiple empirical studies (Diodato *et al.*, 2023; European Commission, 2023; Freeman, 2018; IASA, 2020; Krysovaty *et al.*, 2024). Thus, achieving climate neutrality in the digital era necessitates a unified vision that leverages sustainable digitalization as a catalyst for environmentally sustainable, socially just, and economically responsible development. This involves rethinking digitalization's purpose, ensuring it supports decarbonization while enhancing energy efficiency, automating production, improving supply chain transparency, and enabling data-driven

climate governance. The ultimate goal is to create a sustainable, innovative digital infrastructure that minimizes emissions and optimizes resource use.

The twin transition requires strong public-private coalitions, engaging policymakers, industry leaders, academia, and civil society to drive coordinated action. Ensuring climate neutrality demands that commitments to green policies and multilateral agreements be continuously reassessed through the lens of sustainable digitalization. Additionally, the digital divide remains a major challenge, as unequal access to digital competencies directly affects the pace and effectiveness of the transition. Many businesses and public institutions lack the digital skills needed to harness technology for climate-neutral transformation (Đorić, 2022). Thus, both policymakers and business leaders must enhance their digital literacy to regulate, implement, and accelerate sustainable solutions effectively.

At the global level, sustainable digitalization requires advancing scientific research and supporting R&D in green-digital innovation. While scientific trailblazers emphasize the importance of understanding the complexity and trade-offs in planetary sustainability, where economic, technological, and social systems interact dynamically (Espinosa and Walker, 2017), a significant regulatory and ethical gap persists in defining standards for green-digital integration. A critical step forward is the development of global methodologies for assessing the environmental footprint of digital technologies and ensuring that sustainable digitalization aligns with climate goals. Given the rising importance of data as a production factor alongside land, labor, and capital, its governance must be structured to reinforce the green transition and climate-neutral digital transformation.

Thus, the above considerations form a kind of essential bridge in understanding sustainable digitalization as a factor in minimizing the gaps and inequalities of the double green-digital transition on the way to climate neutrality of the global economy. However, a crucial aspect of harmonizing the green-digital transition is to meet the needs and demands of the climate-neutral economy in terms of technology and digital solutions. In many areas, this requires a powerful "innovation leap," as the low-carbon solutions that the global economy needs are often in their embryonic stages of development or have not been sufficiently tested for mass consumption. Such an innovative "acceleration" of the green-digital transition is an important prerequisite for a harmonious and synchronized movement towards zero emissions. However, it requires significant strategic support. The analysis of the European Union's foresight in recent years (EU, 2023) in the areas of the double transition, climate neutrality, and sustainable future has allowed us to summarize the following critical areas of innovation in the short and long term (Table 1). It is worth noting that in the current context of digital globalization, countries can gain numerous benefits from the "leap" to smart cities, buildings, transportation, agriculture, smart energy, etc. This effect is cumulative for the economy, as it stimulates progress in various industries, the development of new markets, and the emergence of new opportunities for global leadership.

The table below summarizes short-term and long-term digital innovation priorities across sectors. It highlights how current applications, such as smart farming or passive

buildings, evolve into more advanced long-term solutions, including genetic engineering in agriculture or hydrogen-powered transport (Table 1).

Table 1: Digital innovation focuses for the green transition

<i>Fields</i>	<i>Time period</i>	
	<i>Wave 1. Present and short-term perspective (until 2030)</i>	<i>Wave 2. Strategic long-term perspective (until 2050)</i>
Agriculture	Smart farming, agro-ecological practices, and integrated sensor systems in the soil	Digital twins for monitoring land plots, Genetic editing of plants, selection by design, use of advanced biotechnology
Energy	Renewable energy sources, smart grids, and lithium-ion batteries	Wave energy, long-term energy storage systems, hydrogen production through pyrolysis, nuclear fusion
Construction	Passive buildings, digital building logs, and integrated design tools	Building Information Models (BIM), high-performance buildings with automated control systems
Heavy industry	Electric arc furnaces, water from recycling systems, and gas recycling in the mining and metals industry	Improved recycling methods, microbial recycling of plastic waste
Transportation	Electrification of transport, autonomous vehicles, and 3D printing in the production of automotive components	Modularity and virtual coupling in rail transport, coordinated automated road transport, hydrogen airplanes, and fully autonomous vehicles.

One of the barriers to innovative development in the field of green-digital transition is that digitalization is not yet being laid down at the state level as a cross-cutting and widespread priority in many countries. Despite the existence of a large number of programmatic initiatives, agreements, and documents to strengthen the green transition, the lion's share of them do not provide for direct benefits from digital technologies, platforms, programs, and SMART systems (Roussilhe, 2025). Many national legislative frameworks still use traditional approaches to regulating the "physical" world, neglecting the possibilities of using digital tools to achieve sustainable development outcomes and comply with regulatory requirements. This also applies to the lack of adaptation and flexibility of legislation in matters of dual transition.

Overcoming this barrier requires the development of at least 3 areas:

1. Digitalization of national economic systems, taking into account the criteria of climate sustainability.
2. Transparent monitoring and reporting on the implementation of legislation and achievement of climate goals.

3. Subsidiarity and decentralized management to stimulate collective action and identify clear needs.

It should be noted that all of the above digital solutions can be grouped into certain strategically important functional areas that they provide. Currently, there are 4 digital "accelerators" of global development provided by digitalization (Chuard *et al.*, 2022):

Accelerator 1 - Unprecedented transparency. This approach is based on the use of digital technologies to increase data transparency. Open access to information creates opportunities for greater involvement of the public and organizations in decision-making processes, as well as for accountability. Open data contributes to building trust and more effective governance.

Accelerator 2 - Intelligent Systems. The use of artificial intelligence and collective intelligence technologies to create complex systems that can collect, analyze, and adapt to changes in the environment. Such systems can respond quickly to climate challenges, optimize resource management, and increase the efficiency of solutions.

Accelerator 3 - Augmented Reality. Technologies that combine real and virtual worlds open up new opportunities for interaction. The introduction of virtual reality allows us to create new educational formats, raise awareness of climate challenges, and develop interactive platforms for collaboration.

Accelerator 4 - Mass cooperation. Thanks to increased digital connectivity, people from all over the world are able to unite, collaborate online, share resources, implement projects, and create new forms of social movements. Such cooperation increases the effectiveness of solving global problems and contributes to the development of innovative strategies.

By analyzing data from the open global database of 370 environmental projects (SDA, 2025), we have synthesized the following digital accelerators categorized by their respective directions in the implementation of the green transition across various sectors (Figure 3). The impact weight of each accelerator for each area of climate-digital initiatives is calculated according to the share of projects implemented using digital solutions within that accelerator.

Figure 3 quantifies the distribution of digital accelerators across climate-digital projects. It highlights both the maturity of some accelerators and the untapped opportunities of others, pointing to areas where policy support is most needed. The data show that transparency and intelligent systems dominate the current landscape, while newer accelerators such as digital education and personalization are emerging but are less widespread. Thus, ensuring unprecedented transparency is key to the development of data analytics and digital tools for climate management, as well as for environmental monitoring and preservation. The development of the latter also requires the integration of virtual (or mixed) reality, which is also relevant for the construction and development of smart cities. At the same time, intelligent systems are critical for the development of energy management, resource management, and circular practices, for which mass cooperation is also a digital accelerator.

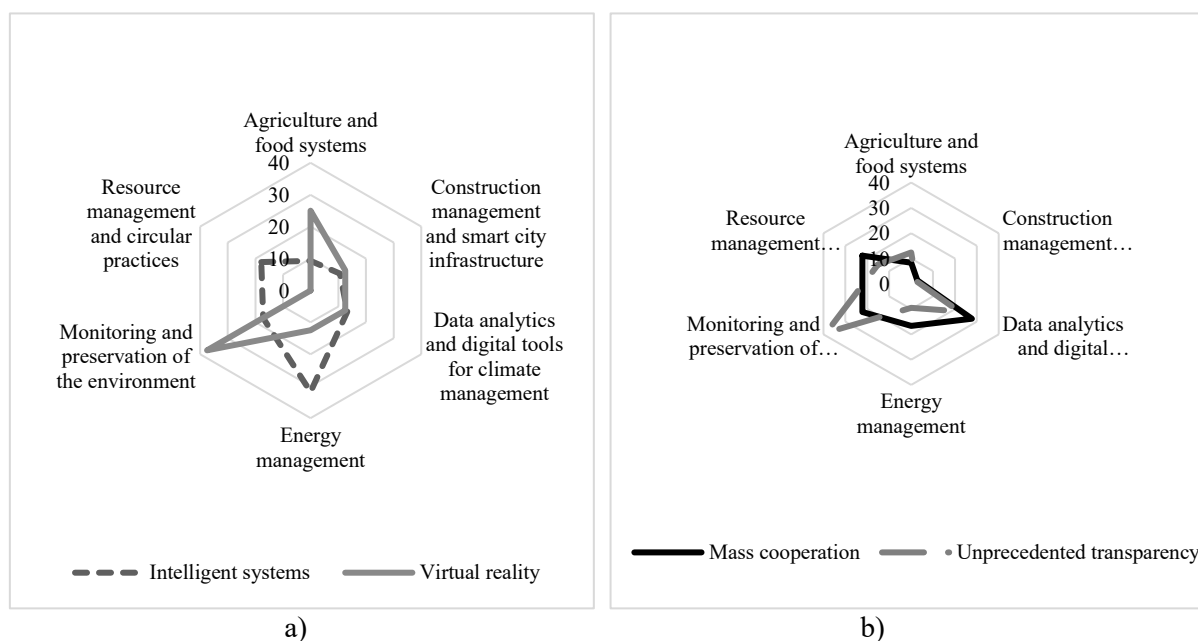


Figure 3: Digital accelerators for the development of certain areas of climate neutrality (share, %)

It is appropriate to highlight the following four additional digital accelerators, which were additionally identified based on the case studies of climate-digital projects:

Accelerator 5. Smart personalization. This area seems to be quite promising, as digital technologies allow creating personalized solutions for users, taking into account their needs, behavior, and preferences. For example, mobile applications can provide individualized advice on how to reduce one's carbon footprint, optimize energy consumption, or participate in local environmental initiatives.

Accelerator 6. Decentralization of data management. Blockchain technologies provide decentralized access to data, which increases trust in the management of climate resources and finances. This will allow for transparent tracking of climate initiatives.

Accelerator 7. Synergistic platforms. This accelerator envisages the creation of integrated digital platforms that bring together governments, businesses, civil society, and academia to address climate challenges. Such platforms allow for coordination of efforts, exchange of data and best practices, and development of joint innovative solutions.

Accelerator 8: Digital education and awareness raising. This accelerator involves the introduction of digital tools for climate neutrality education and awareness.

This typology demonstrates how digitalization accelerates sustainability in diverse sectors, from smart agriculture and renewable energy to mobility and waste management. On the other hand, the digital framework of a climate-neutral economy must be sufficiently resilient to the challenges of digital development. The analysis allowed us to identify the following challenges for the successful implementation of climate-digital projects in terms of sustainable digitalization (Table 2).

Table 2: Problematic challenges in the context of sustainable digitalization

<i>Challenge</i>	<i>Probable reason</i>	<i>Problem setting</i>
A fragmented landscape	The digital toolkit for climate projects traditionally includes a variety of tools for data collection, analysis, modeling, visualization, and communication.	These tools work in isolation, in different data formats, interfaces, and with different technical requirements. The fragmented nature of the current landscape creates challenges in creating a coherent and streamlined IT workflow for climate projects.
Data compatibility	Climate projects rely on a variety of data sources, including satellite imagery, climate models, sensor networks, and even social media feeds.	Integrating and reconciling such data into a coherent toolkit can be a significant technical challenge.
Lack of usability	Differences in data structures, programming languages, and underlying technologies	Difficult to use and scale, a lack of inclusiveness
Accessibility and usability	Platforms and tools that are difficult to understand	The difficulty of attracting the attention of stakeholders, including academics, politicians, and the real economy.

The challenges outlined in table 2 can be systematically linked to targeted mitigation strategies that support sustainable digitalization. The fragmented landscape of digital tools highlights the urgency of creating interoperable architectures and standardized data ecosystems. Such measures enable cross-sectoral integration and reduce transaction costs in climate governance. Data compatibility issues emphasize the need for open-source protocols and international data-sharing frameworks. These approaches foster transparency, comparability, and scalability of digital solutions across jurisdictions. Addressing usability and accessibility barriers requires user-centered design and inclusive digital literacy programs. This ensures that technological diffusion does not exacerbate social inequalities but instead strengthens the adaptive capacity of vulnerable actors. Finally, the challenge of limited stakeholder engagement calls for participatory, multi-stakeholder platforms. By integrating policymakers, industry, academia, and civil society into collaborative ecosystems, digital innovation can be transformed from isolated interventions into systemic accelerators of the twin transition.

Summarizing the findings of the preceding analysis, overcoming the identified challenges necessitates incorporating at least five key components within the sustainable digitalization and climate change:

First, Climate Monitoring and Data Analysis Systems – the deployment of advanced digital tools for tracking and assessing climate change dynamics, enabling precise and real-time environmental monitoring.

Second, Big Data for Climate Assessment and Forecasting – the utilization of large-scale data analytics to evaluate the current state of climate change and predict its long-term impacts, supporting informed decision-making.

Third, development of Information Platforms and International R&D Clusters – The establishment of collaborative digital ecosystems that facilitate research, development, and implementation of innovative technologies in energy efficiency, renewable energy, and other areas essential for greenhouse gas reduction.

Fourth, the integration of digital tools into climate diplomacy and green communications involves enhancing digital infrastructure, such as web portals, mobile applications, social networks, and educational platforms, to actively engage stakeholders, including society, businesses, and governments, in decision-making processes. This approach enhances awareness regarding opportunities, strategic directions, and financial mechanisms for supporting green transformation projects.

Fifth, advancing Digital Educational Platforms and Collaborative Research Programs in Climate Management – The development of integrated learning environments aimed at addressing knowledge gaps, strengthening project resources, and fostering an environmental mindset through digital education.

Thus, the digital framework of a greener, sustainable future is fundamentally structured around critical digital technologies and strategic development areas, collectively forming an integrated system for advancing sustainability goals. The concept encompasses both established digital solutions and emerging innovations, ensuring a dynamic and adaptive approach to addressing climate challenges. At its core, sustainable digitalization serves as the foundation of this framework, emphasizing principles such as digital inclusion, equitable access, climate responsibility, economic feasibility, and environmental resilience. The expected outcomes include achieving net-zero emissions across key economic sectors, maintaining productivity through the digital transformation of industrial and economic processes, and enhancing climate resilience through advanced data-driven governance and policy implementation. The findings confirm that sustainable digitalization constitutes the backbone of the green–digital transition.

Discussion

The findings of this study underscore the strategic significance of sustainable digitalization as both an enabler and accelerator of the global green transition. The proposed three-level harmonization model reveals that synergy between digital and green agendas is not merely complementary but essential for achieving systemic climate neutrality. It highlights how digital technologies can drive decarbonization, resource optimization, and circularity across economic sectors. The typology of digital accelerators and analysis of over 370 climate-digital projects also provide empirical validation of the role of digital tools in delivering scalable, cross-sectoral sustainability outcomes. At a comparative global level, the results suggest that regions with stronger digital infrastructures (e.g., the EU and North America) demonstrate more advanced integration of intelligent systems and transparency tools, while emerging economies prioritize mass cooperation and decentralized platforms as cost-effective enablers of participation. This asymmetry highlights not only technological divergence but also

differentiated pathways to climate neutrality, underscoring the need for tailored policy responses rather than a one-size-fits-all approach.

Thus, the authors identify some discussive limitations that must be acknowledged.

First, the technological rebound effect remains a substantial challenge: while digital technologies offer efficiency gains, they also increase overall energy demand, particularly in the case of high-performance computing, data centers, and AI systems. Without decarbonizing the energy supply that powers digital infrastructure, the environmental benefits of digitalization risk being offset by its carbon footprint.

Second, data compatibility and fragmentation issues pose significant constraints to the large-scale integration of digital tools in climate governance. The lack of standardized data formats, interoperable platforms, and open-access climate data repositories limits the scalability and replicability of successful digital interventions.

Third, there is a governance and regulatory gap. Many countries still treat digitalization and sustainability as parallel rather than converging priorities, resulting in fragmented policies, insufficient coordination, and missed opportunities for synergy. The absence of clear standards to evaluate the environmental impact of digital tools further hinders the development of coherent sustainability strategies.

Fourth, another limitation of this study is the reliance on secondary databases rather than primary data collection. While the use of the Sustainability in the Digital Age database ensured broad coverage and methodological transparency, the absence of surveys, interviews, or direct stakeholder engagement may limit the depth of contextual insights. Addressing this limitation will require future research that incorporates mixed-method approaches, combining large-scale databases with qualitative evidence from stakeholders directly involved in the twin transition.

Thus, these discussion points not only clarify some contextual boundaries but also define key directions for future research. The authors intend to deepen the exploration of these limitations by developing metrics for evaluating the net carbon footprint of digital technologies, assessing the effectiveness of digital inclusion policies in accelerating climate innovation, and designing governance frameworks that integrate sustainability-by-design principles into digital infrastructure planning.

Conclusion

The study has demonstrated that sustainable digitalization is not merely a technological trend but a fundamental catalyst for transforming the global economy toward climate neutrality. Moreover, sustainable digitalization provides a dual-value proposition: enabling substantial reductions in greenhouse gas emissions through digital optimization, and fostering systemic innovation that reshapes production, consumption, and governance models across sectors.

The integration of sustainable digital technologies (such as artificial intelligence, blockchain, big data analytics, and the Internet of Things) has been shown to enhance operational efficiency, reduce energy intensity, and enable circular economy practices.

However, their transformative potential becomes fully effective only in the presence of coordinated international frameworks, inclusive digital infrastructure, and cross-sectoral innovation ecosystems that ensure equitable and strategic diffusion of digital tools. The proposed three-level model for harmonizing the digital-green transition offers a strategic roadmap for embedding sustainability principles into digital transformation. To ensure maximum effectiveness of the green transition, this model must be based on globally aligned climate neutrality objectives, integrated cross-sectoral innovation efforts, and enabling policy environments that foster data transparency, ethical digital governance, and systemic interoperability.

A set of eight digital accelerators was classified by function and sectoral relevance. Such accelerators cover, but are not limited to, intelligent systems, mass cooperation, smart personalization, and decentralized platforms that form a functional infrastructure for scaling sustainability outcomes. Their impact analysis validates the growing role of digital tools as implementation mechanisms for both short-term and long-term decarbonization strategies. At the same time, the research reveals critical systemic barriers that constrain progress: digital fragmentation, lack of regulatory coherence, unequal access to technology, and the carbon footprint of digital infrastructure. These challenges underline the importance of reforming digital governance, standardizing data ecosystems, and embedding climate metrics into all phases of technology design and deployment. Accordingly, there is an urgent need to develop integrative policies that position sustainable digitalization as a core foundation of climate-neutral economic systems. Achieving this requires a shift away from fragmented, sector-specific digitalization toward a holistic approach rooted in sustainability-by-design principles—one that seamlessly aligns technological progress with the goals of climate responsibility and long-term environmental resilience.

Overcoming these barriers requires reforming digital governance, standardizing data ecosystems, and embedding climate metrics throughout technology lifecycles. Future research will build on these findings by advancing methodologies for assessing the net environmental impact of digital technologies, exploring governance models for twin transitions, and formulating evidence-based recommendations for governments, industries, and civil society.

In conclusion, sustainable digitalization should be recognized not as a supporting tool but as a core foundation of climate-neutral economic systems. Achieving this vision demands a decisive shift from fragmented digitalization toward a holistic, sustainability-by-design paradigm—one that unites technological innovation with climate responsibility and long-term environmental resilience.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

<i>Contribution</i>	<i>Author 1</i>	<i>Author 2</i>	<i>Author 3</i>	<i>Author 4</i>	<i>Author 5</i>
Conceived and designed the research or analysis	Yes	No	Yes	Yes	No
Collected the data	No	No	Yes	Yes	Yes
Contributed to data analysis and interpretation	Yes	Yes	No	No	No
Wrote the article/paper	Yes	Yes	No	No	No
Critical revision of the article/paper	No	Yes	No	Yes	No
Editing of the article/paper	No	Yes	Yes	No	Yes
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Project Administration	Yes	No	Yes	No	No
Funding Acquisition	No	No	No	No	No
Overall Contribution Proportion (%)	20	20	20	20	20

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